SPECTRUM MANAGEMENT IN TELEMETRY NETWORKS

Author: Jemilatu Fofanah
Advisors: Dr. Farzad Moazzami, Dr. Richard Dean, Dr. Yacob Astatke
Department of Electrical and Computer Engineering
Morgan State University
jefof1@morgan.edu

ABSTRACT

Spectrum efficiency is the key challenge in modern telemetry systems. Network telemetry requires moving from a dedicated link structure to a network structure which is a very complex problem and requires spectrum management tools. A mixed network structure has been previously proposed for networked telemetry which employs a combination of cellular and Ad-hoc networks. Significant improvements in QoS and clustering of the complex aeronautical networks have been observed and published in several venues. However in the earlier work routing within the Ad-hoc clusters has not been addressed and the clustering has been done using an enhanced K-means clustering. In this paper, a well known clustering algorithm is adopted in the mixed network concept and clustering of the Ad-hoc nodes are optimized based on shortest route to the gateway and minimum hop count criteria. The proposed clustering technique in this paper leads to a jointly optimized cluster-topology and gateway-selection solution a complex aeronautical network. Simulation results towards the end of this paper illustrate that with the proposed method, cluster configuration is locally optimized and the best gateway for each cluster is successfully selected. With addition of traffic measures to the consideration in the routing, the proposed solution will leads to efficient spectrum allocation and improved QoS.

KEYWORDS

Mixed Network, Ad- hoc, Clustering, Dijkstra, Routing. Spectrum Efficiency, QoS.

INTRODUCTION

In aeronautical telemetry, extra measures needs to be taken to guarantee reliable and continuous communication for the Test Articles due to long range paths and sudden changes in the channel topology. Today's telemetry technology requires line-of-sight communication between the ground station and the Test Articles [1]. High ground speed of the mobile nodes is another factor which needs to be accounted for in the network design. In the bid to move to an enhanced network telemetry infrastructure, TRMC launched the Integrated Network Enhanced Telemetry (iNET) project. The iNET project seeks to enhance the current dedicated RF links from the Test Articles (TAs) to the ground station (GS).The traditional IRIG-106 point-to-point standard is used in aeronautical telemetry application to ensure inter-operability between Test Articles (TAs) and the ground station (GS). [2] [3]

Morgan State University research offers to provide an optimal solution for two significant needs as proposed by the Central Test and Evaluation Investment Program(CTEIP) which initiated the iNET project. They are: "Providing a dynamic resource allocation (allocates resource to TAs with respect to their demand) environment between the TAs and GS which helps with the efficient use of the available spectrum" and "Providing reliable coverage for TAs that are outside the footprint of the Base Station in the proposed telemetry environment".

Previously a mixed network architecture has been proposed by MSU and it is shown that a cellular-Ad-hoc hybrid network can be used to provide coverage for TAs that are beyond the coverage area of the GS, while maintaining the desired level of QOS for all the TAs in the network. The mixed network uses clustering techniques to partition the aggregate network into clusters or sub-networks based on properties of each TA, which currently include signal strengths and location [3] [4] [5].

The mixed network management technique is dynamic in all senses and ensures connectivity at any given time. It is shown that, this architecture can be used to provide seamless communication to wireless TAs that are beyond the coverage area of the ground station, while maintaining the desired level of QOS for all TAs in the network [6].

Figure 1 shows a typical aeronautical communication network with several aircrafts scattered around a ground station (GS)/Central Unit.

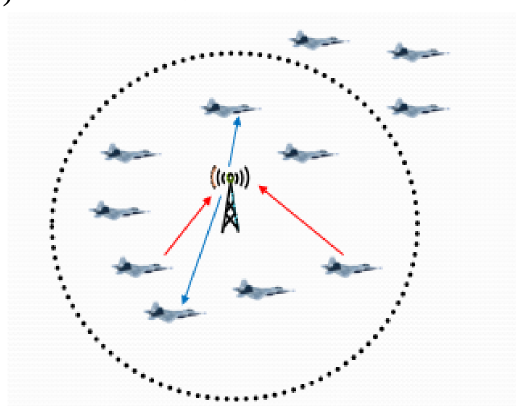

Figure 1: A snap shot of an aeronautical network

Due to high distance and/or obstacles such as mountains between a Test Article and the ground station, at times the line-of-sight (LOS) component of the channel might not exist for a number of TAs. If the LOS is lost, the communication between the over the horizon articles and the GS must be based on reflected paths and other multipath components. This comes with huge limitations and reliability issues. Recently cooperative networking has gained huge grounds for being the ultimate solution to address the over the horizon nodes problem. The proposed mixed network architecture in fact is a realization of cooperative networking technology which details

the clustering and routing algorithms for spectrally efficient spectrum management. In a parallel effort in Morgan State University, the mixed networking research is extended to offer a similar network management technique to decongest the cellular network by offloading high bandwidth data users to compatible local area networks.
In this paper, preliminary results of joint optimization of clustering and routing are presented with the details of the proposed algorithm for network management method.

MIXED NETWORK

The basic idea behind mixed networking is classifying all Test Articles in the network into two groups i) TAs that can directly communicate with the ground station (cellular nodes) and ii) TAs that are currently or permanently over the horizon (Ad-hoc nodes). After this classification, at the boundary of the cellular and Ad-hoc regions, several gateways are identified to relay the information between neighboring Ad-hoc nodes and the infrastructured network. The benefit of this structure is the expanded coverage area of a ground station to communicate with the over the horizon nodes.
While this technique provides a direct or an indirect link to all of the TAs, managing the Ad-hoc nodes and selecting appropriate gateways for seamless communication, are two remaining problems that needs to be solved in order to realize such structure.
Figure 2 shows a simplified mixed network environment in which classification to cellular (CM) and Ad-hoc (AHM) nodes are completed and a single gateway (GM) node is selected. Existence of the gateway node ensures the connectivity of cellular and ad-hoc networks.

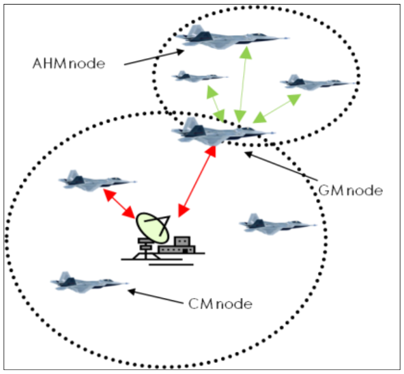

Figure 2: A simple mixed network topology

In a complex environment where there are several hundereds or thousands of nodes such as airplanes and sensors in a battle ground, the Ad-hoc network becomes extremenly populated and any routing mechansim to a particlaur gateway node becomes potentially inefficient. Even if a nonefficient routing mechanism is implemented, buffer size and the capacity of the gateway nodes limits the number of supported TAs. Since this a dynamic network and all of the nodes are mobile, each node is capable of being in either cellular, Ad-hoc, and gateway mode at any given time. Therefore the cost of opearting as a gateway must kept at minimum.

The overall performance of this complex network depends on the management of the Ad-hoc network and its coupling with the cellular network. Figure 3 visualizes this problem where 150 TAs are shown in cellular and Ad-hoc modes.

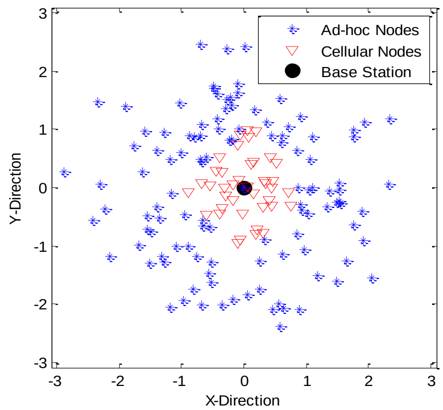

Figure 3: A complex network environment

To address the issue of populated Ad-hoc network and to enable the routing mechanism to support minimum delay indirect communication of the Ad-hoc nodes with the base station, the Ad-hoc nodes are grouped into several sub networks or “clusters”.

In the previous works, clustering of the Ad-hoc nodes was accomplished by using an enhanced K-means clustering algorithm to assign nodes into several clusters. In those efforts the criteria to update the centroid location within the K-means algorithm has been modified to include traffic and interference measures in addition to the traditional Euclidean distance measure. Significant improvements in overall QoS and delay of the clustered networks have been reported in [6], [7]. However routing within the clusters are not considered in the previous works and gateways are not identified for each cluster, and the optimization is performed to find the optimum cluster configuration based on the physical location of the nodes and the traffic intensity of the cluster.

In this work clustering of the Ad-hoc nodes are performed such that the cost of routing from each node to the gateway is minimized while selecting the optimum gateway for each cluster. This joint optimization results in the best overall configuration of the final network in the sense that it provides minimum delay access to the base station while cutting the unnecessary overhead cost of routing to a poorly selected gateway.

GATEWAY SELECTION

The important assumption is the fact that every node in cellular cluster is a potential gateway. Therefore the initial set of possible getaways is the entire cellular set. In order to effectively select appropriate gateway nodes, the number of potential gateways is reduced by testing their ability to reliably communicate with the Ad-hoc cluster. This simply boils down to imposing an SNR threshold which needs to be met by the gateway to the closest Ad-hoc node in any direction. This is the first step toward a reduction in the number of possible gateway set. The remaining potential gateways are marked in green circles in figure 4.

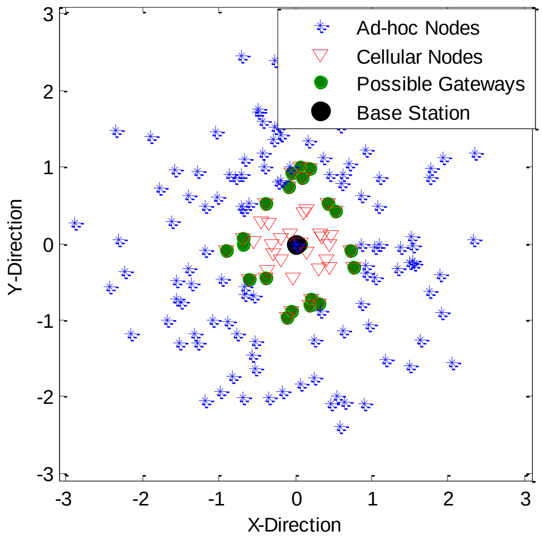

Figure 4: Potential gateways in the cellular network

Selection of the optimum gateways from the remaining potential gateways is done such that the selected set of gateways would provide overall minimum cost routing to all of the neighboring Ad-hoc nodes. In this step route discovery is performed from all of the Ad-hoc nodes to all of the potential gateways. In order to keep the order of computation as low as possible, the Dijkstra routing algorithm is used to simply compute the lowest cost route from each Ad-hoc node to the possible gateways.

ROUTE DISCOVERY

Routing is the process during which data packets (information) are forwarded from one machine or device (technically referred to as a node) to another on a network until they reach their destinations. Managing the delay in the network in the most efficient manner that will ensure reliable support to real-time applications(voice, video and data) used in the telemetry environment hence maintaining good network performance. For this application Dijkstra routing algorithm is used since it is computationally efficient as the network grows. Dijkstra algorithm utilizes linear programming wherein once a path is declared as the minimum path, all future decision flow from that path [8]. Dijkstra algorithm finds the feasible path from source to destination which costs less than any other possible route between the source and the destination nodes. This cost function will favor paths that will incur minimum distance and discourage those with high hop count while selecting a path with minimum distance will maximize the Signal- to-Noise (SNR) of nodes in the network. The process of Dijkstra can be described as follows; (i) starts out with the source node (which can be in the ad-hoc cluster network) reach out for the nodes it can connect with and their associated cost,(ii) pick the lowest cost,(iii)See what you can reach from this new node and update cost if they are cheaper than the previous ones,(iv) go back to (ii) until all nodes are included. With just one pass of the Dijkstra routing algorithm the least cost route from the Ad-hoc nodes to each possible gateway is obtained. Note that in traditional ad hoc networks route discovery occurs with significant overhead and potentially poor results.

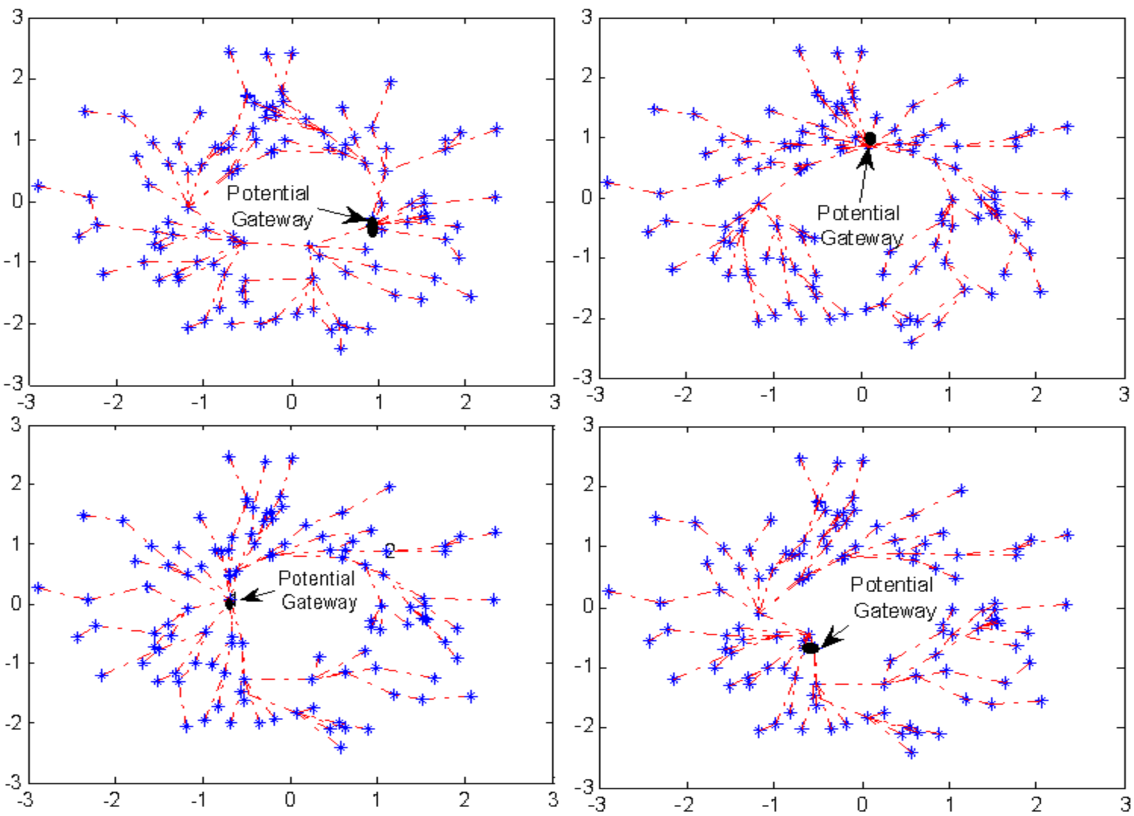

Figure 5: Sample of discovered routes to potential gateways by Dijkstra algorithm

Figure 5 shows the discovered routes from each Ad-hoc node to a potential gateway by Dijkstra routing algorithm. In this figure the discovered routes only for four potential gateways are shown. At each pass of the Dijkstra routing, a table of route cost and hop count is recorded.

JOINT OPTIMIZATION

At the end of route discovery, the optimum set of gateways are selected from the potential gateway set such that the average cost and average hop count of the routes from the Ad-hoc nodes to the corresponding gateways are jointly minimized. The selection of optimum gateways instantly generates the optimum clusters as well. This is done by associating each Ad-hoc node to the minimum cost gateway. As result of this joint optimization, best set of gateways are selected and Ad-hoc nodes are optimally clustered to insure minimum cost of routing to the gateway connecting them to the cellular network.

Figure 6 shows the selected gateways and associated cluster to each gateway.

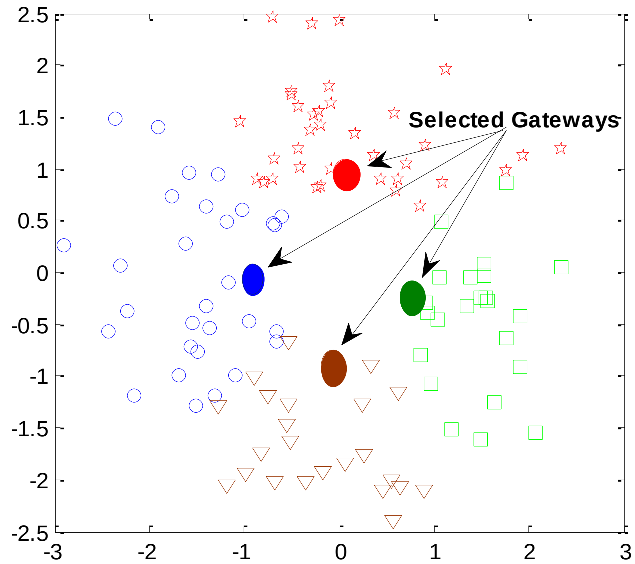

Figure 6: Optimum gateways and associated clusters

From figure 6 it is observed that, the associated clusters with the selected gateways are in the close proximity of each other. This is a result of the fact that physical distance plays a huge role in determining the SNR of each path and high costs are assigned to longer paths and the routing thru such paths are discouraged.

RESULTS AND CONCLUSIONS

A method for organizing a mixed network of cellular and Ad-hoc users has been demonstrated. This method offers performance advantages in SNR and QOS performance for such networks. The joint optimization of mixed networks is a key ingredient in the frequency management of the iNET network with large populations of OTH Test Articles.

Results of this work demonstrate solutions that adapt to both SNR and hop count in the selection of gateways and clusters. This method can be expanded to incorporate traffic and interference as has been done in earlier work. Development of such methods should provide a complete and optimal method for organizing of networks and for spectrum management.

REFERENCES

[1] Q. Z. P.D. Agrawa, Introduction to Wireless and Mobile Systems, 2002.

[2] O. Babalola, "Optimal Configuration For Nodes in Mixed Cellular And Ad hoc Network for iNET," in *ITC 2007 Conference*, Las Vegas, October 2007.

[3] Y.Astatke, "Disatnce Measures for QOS Performance Measurement in Mixed Network," *In ITC 2009 Conference,* Occtober 2009.

[4] O. Babalola, "Optimal Configuration for Nodes in Mixed CEllular and Ad-hod Network for iNET," in *International Telemetry Conference,* Las Vegas, 2007.

[5] St.Ange.L., "The Optimization of Node Configuration in a Mixed Network for Quality of Service," in *ITC*, San Diego, 2008.

[6] Y. Astatke, "Distance measures for QoS PErformance Management," in *International Telemetry Conference*, San Diego, 2008.

[7] A. Babalola, "Optimal Configuration For Nodes in Mixed CEllular and Ad-hoc Network," Baltimore.

[8] W. Stallings, High Speed Networks and Internets, New jersey: Prentice Hall, 2002.

[9] O. Gwanvoma, "Mixed Network Clustering with Multiple Ground Station and Node Preferences," in *International Telemetry Conference,* San Diego, 2010.

[10] O. Gwanvoma, "Miced Network Clustering with Multiple Ground Station and Node Preferences," in *International Telemetry Conference*, San Diego, 2010.